

Technical Report 888

AD-A224 038

Strategies of Computer-Based Instructional Design: A Review of Guidelines and Empirical Research

Dudley J. Terrell
Anacapa Sciences, Inc.

May 1990

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS --	
2a. SECURITY CLASSIFICATION AUTHORITY --			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE --			5. MONITORING ORGANIZATION REPORT NUMBER(S) ARI Technical Report 888	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) ASI690-324-89			7a. NAME OF MONITORING ORGANIZATION U.S. Army Research Institute Aviation Research and Development Activity	
6a. NAME OF PERFORMING ORGANIZATION Anacapa Sciences, Inc.	6b. OFFICE SYMBOL (If applicable) --	7b. ADDRESS (City, State, and ZIP Code) ATTN: PERI-IR Fort Rucker, AL 36362-5354		
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 489 Fort Rucker, AL 36362-5000	8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. Army Research Institute for the Behavioral and Social Sciences	8b. OFFICE SYMBOL (If applicable) PERI-I	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER MDA903-87-C-0523	
8c. ADDRESS (City, State, and ZIP Code) 5001 Eisenhower Avenue Alexandria, VA 22333-5600	10. SOURCE OF FUNDING NUMBERS			
	PROGRAM ELEMENT NO. 63007A	PROJECT NO. 795	TASK NO. 3309	WORK UNIT ACCESSION NO. C06
11. TITLE (Include Security Classification) Strategies of Computer-Based Instructional Design: A Review of Guidelines and Empirical Research				
12. PERSONAL AUTHOR(S) Terrell, Dudley J. (Anacapa Sciences, Inc.)				
13a. TYPE OF REPORT Interim	13b. TIME COVERED FROM 88/06 TO 89/09	14. DATE OF REPORT (Year, Month, Day) 1990, May	15. PAGE COUNT	
16. SUPPLEMENTARY NOTATION All research on this project was technically monitored by Mr. Charles A. Gainer, Chief, U.S. Army Research Institute Aviation Research and Development Activity (ARIARDA), Fort Rucker, Alabama.				
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	Computer-based instruction Part-task training	
05	08		Computer-assisted instruction Instructional development	
			Computer-based training (Continued)	
19. ABSTRACT (Continue on reverse if necessary and identify by block number) > A survey of literature was conducted to examine empirical research for the numerous guidelines and recommendations that have been published about design strategies for computer-based instruction. The guidelines and experiments were categorized as pertaining to (a) strategies for presenting instructional material, (b) strategies for questioning and interactivity, or (c) strategies for programming response feedback and remediation procedures. Strategies for presenting instructional material were analyzed in literature on orienting instructions and objectives, stimulus display duration, sequencing instruc- tional material, sequencing levels of difficulty, graphics, and review of material. Strategies for questioning and interactivity were analyzed in literature on prelesson questions, question types, question placement, number of questions, and answering ques- tions. Strategies for programming response feedback and remediation procedures were analyzed in literature on feedback for correct and incorrect responses, latency of feed- back, and placement of feedback. Each guideline was classified according to (Continued)				
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Charles A. Gainer			22b. TELEPHONE (Include Area Code) (205) 255-4404	22c. OFFICE SYMBOL PERI-IR

ARI Technical Report 888

18. SUBJECT TERMS (Continued)

Instructional design
 Training effectiveness
 Training strategies
 Learning

19. ABSTRACT (Continued)

whether authors of instructional guidelines made recommendations that contradicted the guideline, and whether empirical research supports the guideline, contradicts the guideline, or does not exist to evaluate the guideline. Very few of the guidelines are supported by empirical research or agreement among experts. Most of the guidelines are contradicted by other guidelines and are insufficiently supported by research. Instructional design guidelines requiring further research are identified.



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Availability Codes	
Dist	Avail and/or Special
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**Strategies of Computer-Based Instructional Design:
A Review of Guidelines and Empirical Research**

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May 1990

Army Project Number
2Q263007A795

Training and Simulation

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FOREWORD

The U.S. Army Research Institute for the Behavioral and Social Sciences performs research and develops programs to improve training effectiveness and to contribute to training readiness. Of special interest are research and development programs that apply computers and other advanced technologies to part-task trainers and training strategies. Research that identifies the most effective strategies for designing computer-based trainers and training programs will enhance the development and procurement of specific part-task training systems required by the Army training community.

This report surveys the literature and evaluates the existing research for computer-based instructional design strategies. Instructional design issues requiring further research and development are identified. With an understanding of the current state of the art in instructional design, training developers (Directorate of Training and Doctrine (DOTD), U.S. Army Aviation Center (USAAVNC)) can design new systems to use the most effective strategies and evaluate the effectiveness of new strategies.

This work was conducted within the Training Research Laboratory program under Research Task 3309, entitled "Techniques for Tactical Flight Training." The Army Research Institute Aviation Research and Development Activity (ARIARDA) at Fort Rucker, Alabama, was responsible for the execution of the work. This work is a part of a Memorandum of Agreement (MOA) between ARIARDA and DOTD, USAAVNC, dated 15 March 1984 and updated in October 1989. This information was provided as a preliminary draft to the DOTD. However, the primary application was a literature review to support research for the empirical development of a total training system for aviation knowledge and skills.



EDGAR M. JOHNSON
Technical Director

STRATEGIES OF COMPUTER-BASED INSTRUCTIONAL DESIGN: A REVIEW OF GUIDELINES AND EMPIRICAL RESEARCH

EXECUTIVE SUMMARY

Requirement:

This literature survey was conducted to examine the empirical research support for the numerous guidelines and recommendations that have been published about computer-based instructional design strategies.

Procedure:

Two types of publications were selected and reviewed: (a) reports of empirical research comparing at least one strategy of computer-based instruction (CBI) with another, and (b) published guidelines for the development of CBI. The guidelines and experiments were categorized according to whether they pertained to strategies for (a) presenting instructional material, (b) questioning and interactivity, or (c) programming response feedback and remediation procedures. Each section of the report begins with a list of guidelines for some aspect of instructional design and a discussion of the recommendations made by the authors of the guidelines. Then the empirical research relevant to each guideline is reviewed, and guidelines that lack research support are identified. Finally, each guideline discussed in the report is classified by whether (a) authors of instructional guidelines made another recommendation that contradicted the guideline, and (b) empirical research supports the guideline, contradicts it, or does not exist to evaluate it.

Findings:

Only 5 of the 57 guidelines reviewed are supported by empirical research. Authors of guidelines agree that CBI should present questions, corrective feedback for incorrect responses, and multiple trials for items that are answered incorrectly. Although some authors do not agree that CBI should present pre-lesson questions or that computers should be programmed to control adaptively the number of trials, empirical research suggests that these strategies are effective.

Although the experimental evidence is not strong enough to justify complete rejection, 8 of the 57 guidelines are contradicted by the results of empirical research. Empirical research tends to contradict recommendations to use graphics often, to provide increasingly informative feedback for successive errors, to train under mild speed stress, to present information before

practice, to randomize the sequence of material, to present part-task training prior to whole-task training, to permit the student to control the presentation of reviews, and to program the computer to control the presentation of reviews.

Finally, 44 of the guidelines have been insufficiently addressed by empirical research. For many of the guidelines, either empirical research has produced mixed results and further research is required, is inconclusive because of inadequate experimental designs, or simply does not exist. Some of the guidelines, however, are self-evident and do not require empirical research. Other guidelines are stated in terms that are too general to evaluate their usefulness. Some are very specific, and an evaluation of the possibility of presenting them generally is required.

Utilization of Findings:

The CBI designer and the educational technology researcher should be aware of the contradictions and potential limitations of the recommendations in the literature. Research should be designed to address the current gaps in knowledge of computer-based instructional strategies. Existing operational problems in part-task training may be addressed in a manner that extends this knowledge. Instructional designers currently working on training development should recognize when a particular strategy is being applied in a case that potentially tests the generality of a recommendation or research result.

STRATEGIES OF COMPUTER-BASED INSTRUCTIONAL DESIGN: A REVIEW
OF GUIDELINES AND EMPIRICAL RESEARCH

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STRATEGIES OF COMPUTER-BASED INSTRUCTIONAL DESIGN:
A REVIEW OF GUIDELINES AND EMPIRICAL RESEARCH

Introduction

Background

Training technology has progressed from Pressey's teaching machines and Link's simulators of the 1920s to the computer-based tutors, part-task trainers and simulators of the 1980s (Benjamin, 1988; Flexman & Stark, 1987). A new field of research and development, called instructional design, has emerged in industry and academia to provide services in educational technology. Textbooks on the application of learning theory to instructional design (for example, Gagné, Briggs, & Wager, 1988), journals specializing in the publication of educational technology research (for example, Journal of Computer-based Instruction, Journal of Instructional Development), and guidelines for the development of computer-based instruction (for example, Alessi & Trollip, 1985; Kearsley, 1986) have been published. Professional organizations, such as the Association for the Development of Computer-Based Instructional Systems and the Computer Systems Technical Group of the Human Factors Society, convene regularly to discuss developments in computer-based instruction research.

Computer-based instruction (CBI) and simulation are rapidly becoming an integral part of military training. Operation of sophisticated weapons systems during fast-paced combat requires a multitude of skills that may be trained most effectively with simulators and part-task trainers. The development of such training technology requires a thorough understanding of (a) the skills and abilities required to operate the systems, (b) theories of learning and principles of instruction, and (c) the state-of-the-art in computer technology.

Over the past decade, an enormous amount of research has been conducted to investigate the training potential of CBI. The majority of this research has had as its primary objective the comparison of CBI with other methods of instruction. Reviewers have often concluded that computers can measurably improve training effectiveness (for example, Eberts & Brock, 1987). However, Clark (1985) suggests that the training effectiveness of CBI is due primarily to effective instructional strategies and not to the medium per se. Most of the media comparison research provides very little information

about effective strategies of computer-based instructional design (Reeves, 1986; Shlechter, 1986).

Procedure

The present survey of literature was conducted to examine the empirical research support for the numerous guidelines and recommendations that have been published about computer-based instructional design strategies. Two types of publications were selected and reviewed: (a) reports of empirical research comparing at least one strategy of CBI with another and (b) published guidelines for the development of CBI. Reports of experiments comparing CBI with other methods of instruction, reports of computer-based instructional development (without experimentation), and reports describing new technology or new applications of existing technology were not considered.

The guidelines and experiments were categorized according to whether they pertained to strategies for (a) presenting instructional material, (b) questioning and interactivity, or (c) programming response feedback and remediation procedures. In the following sections, the guidelines and research in each of these areas are presented. Each section begins with a list of guidelines and a discussion of the recommendations made by their authors. Then the empirical research relevant to each guideline is reviewed. Finally, the guidelines that lack research support are identified.

Presentation of Instructional Stimuli

Designers of CBI must make many decisions about the organization and presentation of training material. They must decide what sorts of events should occur on the monitor, such as tutorials, drills, and simulations, and how long each instructional event should take. They must determine how students should be instructed to interact with a lesson, how graphics can be used most effectively, and whether the student or the computer should control the training variables. This section presents some of the guidelines and empirical research pertaining to orienting instructions, stimulus display duration, sequencing of instructional material, sequencing various levels of difficulty, use of graphics, and review of material.

Orienting Instructions and Objectives

Orienting instructions are directions that are provided to inform students about the nature of the interaction required during a lesson, the operation of a training device, or both. Objectives are statements of the benefits to be realized by the student as a result of successful participation in the lesson or training. Not all recommendations about the presentation of orienting instructions or objectives must be supported by empirical research. If a training device is complicated to operate or unfamiliar to the student, operating instructions obviously are necessary for training to occur. Similarly, if a student must choose from a set of lessons or training devices, statements of objectives may enable the student to select a lesson addressing a particular interest or training deficiency. However, training effectiveness research is required to investigate the possible benefits of orienting instructions or objectives in any particular lesson or with a device that is not difficult to operate.

Guidelines. Authors of instructional design guidelines have four different, and somewhat incompatible, recommendations about the use of orienting instructions and objectives. Statements made about the utility of orienting instructions and statements of objectives include the following:

- they are ineffective and unnecessary,
- they limit the amount or breadth of learning,
- they should be included in CBI design, and
- they should be a student-controlled option.

Hannafin and Hughes (1986) suggest that orienting instructions are typically unnecessary. Although orienting instructions may be necessary for poorly organized lessons, well organized lessons are not enhanced by orienting instructions. Statements of behavioral objectives may be beneficial only when students have had some experience in the use of objectives as orienting activities.

Statements of objectives may enhance training described in the objectives, but they may obscure any incidental training potential of a lesson. Hannafin and Hughes (1986) warn that orienting activities may be effective only for learning that is "context-bound or limited in application" (p. 248). Jonassen and Hannum (1987) and Wager and Wager (1985) state that orienting instructions appear to increase the speed of learning and reduce lesson errors, but they may hinder the retention of lesson material.

Despite the conclusions and recommendations described above, these and other authors still advocate the use of orienting instructions and objectives in CBI. Jonassen and Hannum (1987) advise instructional designers to include cognitive maps and structured overviews to illustrate where topics fit into the content area. Wager and Wager (1985) recommend that lessons inform the student of special conditions and expectations of performance. Alessi and Trollip (1985) state that computer-based tutorials should have a concise and accurate statement of objectives, although not necessarily in behavioral terms. However, they add that this recommendation does not apply to CBI designed for young children. Buehner (1987) suggests that CBI consistently include an overview of the training, describing opportunities for review and reinforcement. According to MacLachlan (1986), "...at the beginning of a computerized tutorial, the student can be told the benefits he can expect by giving attention to the material in the tutorial....It would be desirable, then, to preface a tutorial with instructions indicating the manner in which the student should be watchful" (p. 65). Finally, Jonassen and Hannum (1987) recommend that lesson overviews be presented as an option for the student to choose.

Research. There is very little research support for recommendations about orienting instructions and objectives. Ho, Savenye, and Haas (1986) and Reiber and Hannafin (1986) found no differences between groups of subjects who viewed orienting instructions and those who did not. However, Hannafin, Phillips, and Tripp (1986) found that orienting instructions improved posttest scores when the ensuing lesson followed the instructions after a 5-second interval but not after a 20-second interval.

The research evidence is inadequate to support either the inclusion or exclusion of orienting instructions or objectives in CBI. Furthermore, no research has been located that addresses the assertion that orienting instructions and objectives limit the amount or breadth of learning in CBI.

Stimulus Display Duration

Except in the case of animation, the CBI designer must decide whether a stimulus display should remain on the screen until removed by the student, or should be removed automatically after a prescribed amount of time has passed. If the latter alternative is chosen, the designer must determine optimal durations for displays.

Guidelines. Authors of instructional design guidelines disagree in their recommendations about stimulus display duration. Alessi and Trollip (1985) advocate student control of display duration for the presentation of questions and graphics. However, Eberts and Brock (1984) assert, "If the task can be shortened with no loss of those aspects of the task that are important for training, then more practice trials can be achieved in the same amount of time" (p. 268). Shortening a task may require computer control, not student control, of display durations. Furthermore, Schneider, Vidulich, and Yeh (1982) recommend that training be conducted under mild speed stress; speed stress is difficult to achieve when the control of display duration is left to the student.

Research. Control of display duration was examined in four experiments. Tennyson and Park (1984) compared two strategies of computer-controlled display durations with a condition of student-controlled duration. In one computer-control strategy, display duration increased following correct responses and decreased following incorrect responses. In the other computer-control strategy, display duration decreased following correct responses and increased following incorrect responses. Posttest scores were higher when display duration increased following correct responses and decreased following incorrect responses, but there were no significant differences between the student-control strategy and either computer-control strategy.

Tennyson, Park, and Christensen (1985) and Tennyson, Welsh, Christensen, and Hajovy (1985) each compared two strategies for manipulating trial display duration. In one strategy, display duration increased following correct responses but was unchanged following incorrect responses. In the other strategy, display duration was controlled by the student. Posttest scores were higher for students who used the former strategy.

Two of these three experiments support the recommendation that the computer, rather than the student, control display duration. However, the results of these experiments also suggest that student control of display duration might be appropriate after the student has progressed beyond initial skill or knowledge acquisition. In each of these experiments, a student's response immediately terminated the trial display and initiated the feedback procedure. In the most effective strategy of each experiment, correct responses produced longer display durations. As the frequency of correct responses increased, each subject had more opportunity to respond before a trial was automatically terminated. Therefore, the students who were responding correctly

essentially controlled their own trial durations. Tennyson, Park, and Christensen (1985) and Tennyson, Welsh, Christensen, and Hajovy (1985) showed that student control was not an effective strategy when it was unrelated to the student's correct responding.

All three experiments contradict the recommendations to decrease trial durations or train under speed stress. That is, if correct responses result in longer display durations, successful performance could make the program run slower and probably become less stressful, rather than quicker and more stressful.

Finally, one experiment appears to support student control of display duration. Belland, Taylor, Canelos, Dwyer, and Baker (1985) compared three strategies for controlling duration of a textual display. In one strategy, the student controlled the duration of each lesson frame. In another strategy, the frame duration equalled one second per line of text plus eight extra seconds per frame. In the third strategy, the frame duration equalled one second per line of text plus one extra second per frame. Posttest scores were higher for students using the student-control and the one-plus-eight-second strategy than for students using the one-plus-one-second strategy. While appearing to support the student-control recommendation, the results of the research conducted by Belland et al. (1985) merely indicate that one second per line plus one second per frame is an insufficient amount of time to read text.

The issue of controlling text duration may not require empirical research. Unless the goal of instruction is to increase a student's reading speed, text should not be presented faster than it can be read. However, if research is required, a better test of student control of text duration would be to compare pairs of students of comparable reading speed. One student in each pair should control the display duration for the pair, thereby creating an apparent computer-control condition for the other student.

Sequencing Instructional Material

Instructional designers must decide the sequence in which instructional events occur. For example, lessons could begin with presentations of information, follow with practice drills or questions, and end with remediation. Part tasks could be trained prior to whole tasks. The same subject matter could be trained in a tutorial or information-oriented lesson, a flashcard-type drill, or a simulation or game.

Guidelines. Instructional designers must decide whether the student, the computer, or the designer should determine the sequence of events. Authors of instructional design guidelines offer the following conflicting recommendations:

- always allow the student to control the sequence of instruction,
- never allow the student to control the sequence of instruction, and
- conditionally allow the student to control the sequence of instruction.

Kearsley (1986) recommends that the student control all aspects of sequencing. Specifically, students should be able to get to any lesson or part of the program from a main menu and should be able to decide the order in which they would like to complete the lessons. However, Kearsley adds that the computer should inform students if they choose to skip important prerequisite information. Eberts and Brock (1984) advise that a program should promote a strategy of active search through instructional material, and therefore, should be designed so students can freely access different parts of the material. Buehner (1987) says that instruction should include opportunities for the student to adjust the order of presentation. Alessi and Trollip (1985) recommend that designers provide the capability to browse through the questions in a computer-based test.

Jonassen and Hannum (1987) advocate the opposite position. Claiming it is not effective for students to control the sequence of instruction, they advise: "Do not allow learners to determine the sequence of the instructional content," and "Do not allow an option for learners to skip examples" (p. 14).

However, Jonassen and Hannum (1987) contradict themselves when they advise designers to give "learners with high internal locus of control the ability to sequence the lesson content" (p. 13). Consequently, they suggest that instructional programs include a test for internal locus of control and permit students with a high degree of internal locus of control to sequence the lesson content for themselves. Jonassen and Hannum do not define internal locus of control in their article; however, the phrase was used originally to refer to the tendency of some individuals to believe that their own actions are responsible for the consequences of their behavior (Rotter, 1966). Jonassen and Hannum's recommendation assumes that students who believe they are the causes of their own reinforcers also know the most effective training sequences for themselves. Alessi and Trollip (1985)

recommend that control of sequence be given to advanced students when the subject matter is simple, but not to less advanced students and not if the subject matter is complicated.

In the event that students are not permitted to control the sequence of instruction, effective sequences must be identified and programmed into the lesson. Authors of design guidelines recommend the following:

- information should be presented before practice,
- concrete material should be presented before abstract material,
- chronological ordering of material should be used in preference to random sequencing,
- the sequence of practice material should be randomized, and
- part-task training should sometimes precede whole-task training.

Alessi and Trollip (1985) assert that programs are more efficient and more successful when they begin with the presentation of information. For initial acquisition of information, Jonassen and Hannum (1987) advocate sequences that begin with concrete, real-world experiences and proceed to more abstract experiences. MacLachlan (1986) advocates thematic organization of material and recommends chronological organization as the most effective theme for computer-based tutorials. In contrast, Jonassen and Hannum advise designers to randomize the presentation of practice material during computer-based drills.

Eberts and Brock (1984) recommend that early training should be mostly part-task training, and later training should contain a high percentage of whole-task training. However, Holding (1987) notes that the value of part-task training depends on the tradeoff between task difficulty and the degree of interdependence of the parts of a task. Large tasks that can be broken down into relatively independent parts are more appropriately trained with part-task training.

Research. There is very little research to support recommendations about the allocation of sequence control in CBI. Gray (1987) compared two strategies of sequence control in CBI. In one strategy, students could choose to see a review of each trial, but otherwise the trials were presented in a linear fashion. In the other strategy, students could choose to review the current trial, progress to the next trial, or branch anywhere in the lesson. Students using the

branching strategy performed better on a posttest administered immediately following the instruction than the students using the linear strategy. However, there were no differences between groups on a second posttest administered one week after the lesson.

Except for the results of the follow-up posttest, this experiment appears to support the recommendation that students be allowed to control the sequence of instruction. However, the effectiveness of the linear strategy was not adequately assessed. The student-control strategy may have been merely better than a relatively ineffective strategy of trial sequencing. This does not contradict the possibility that an instructional designer could determine a sequence that is superior to the student-control strategy.

A demonstration that student-control strategy is more effective than an ineffective training sequence does not refute a recommendation that the computer should control the instructional sequence. For example, Barsam and Simutis (1984) compared two trial sequencing strategies in a computer-based course on map contour line interpretation. In both strategies the computer presented a simplified contour map in the upper half of the screen and a three-dimensional depiction of the terrain in the lower half of the screen. The computer cursor could be placed at any location on the map and rotated. Subsequently, the three-dimensional view corresponding to the cursor's position and direction would appear on the lower half of the screen. In the student-control strategy, the student could select the placement and rotation of the cursor on each trial. In the computer-control strategy, the placement and rotation of the cursor was randomly selected on each trial. Students with high spatial ability test scores in the student-control condition had higher posttest scores than students with high spatial ability test scores in the computer-control condition. However, there were no differences between the two conditions for students with medium or low spatial ability test scores.

The results of this experiment cannot be taken to support recommendations for student control of trial selection for high ability students or recommendations against student control for low ability students. As with the Gray (1987) research, this experiment does not demonstrate the effectiveness of the comparison strategy for trial sequencing. It is possible that a random sequence of trials is an ineffective instructional strategy, and students of high spatial ability were simply able to design a lesson that was superior to random trial presentations, while students of low spatial ability were not.

No research was found to support Alessi and Trollip's (1985) recommendation that CBI should present information before practice. Lahey (1981) compared three presentation sequences of rules, examples, and practice trials in a concept learning task: rule-examples-practice, examples-rule-practice, and practice-examples-rule. According to Alessi and Trollip, the first and second sequences should be more effective than the third. However, posttest results revealed no differences among the three sequences.

No research was found to support the recommendations that CBI should present concrete material before abstract material, chronologically order the instructional material, or randomize the sequence of practice material. In fact, the results of Barsam and Simutis's (1984) research could be taken as refutation of the recommendation to randomize the sequence of practice material.

Wightman and Lintern (1985) reviewed empirical research on three strategies of part-task training: segmentation, fractionation, and simplification. In segmentation, a task is divided temporally or spatially into subtasks with identifiable end points. In fractionation, a task is divided into subtasks that are normally executed simultaneously. In simplification, a difficult task is made easier by reducing the complexity of stimuli and response requirements. Although many of the experiments that Wightman and Lintern reviewed did not employ computer-based instructional media, the results typically suggest that segmentation is an effective strategy of part-task training. However, the methods of fractionation and simplification were not necessarily more effective than whole-task training. The effectiveness of part-task training prior to whole-task training appears to be a function of the task partitioning strategy, an issue that may be independent of computer-based instructional design considerations.

A program of research by Tennyson and associates demonstrated the effects of response-sensitive trial sequencing strategies in a concept classification task (Park & Tennyson, 1980, 1986; Tennyson, Park, & Christensen, 1985; Tennyson, Welsh, Christensen, & Hajovy, 1985). In each trial of a concept classification task, a subject was required to identify the category to which a particular example belongs. Park and Tennyson (1980) compared a response-sensitive strategy with random presentation of trials. In the response-sensitive strategy, the trial following each incorrect response contained an example from the same category as the previous incorrect response. The response-sensitive strategy produced higher posttest scores with fewer training trials than the random presentation.

Then, Tennyson, Welsh, Christensen, and Hajovy (1985) compared two response-sensitive strategies. One strategy was identical to the Park and Tennyson (1980) strategy: the trial following each incorrect response contained an example from the same category as the previous incorrect response (hereafter called the previous response strategy). In the other strategy, the trial following each incorrect response contained an example from the same category as the previous example (hereafter called the previous example strategy). Posttest scores showed no differences between these two strategies.

Tennyson, Welsh, Christensen, and Hajovy (1985) then demonstrated that a third strategy was superior to the previous example strategy. In the new strategy, incorrect responses early in the lesson were followed by a trial containing an example from the same category as the previous example, but incorrect responses later in the lesson were followed by a trial containing an example from the same category as the previous response. Tennyson, Park and Christensen (1985) affirmed and extended this finding by demonstrating the superiority of the new strategy over the previous response strategy as well.

Park and Tennyson (1986) found no differences between the previous example and previous response strategies on a computer-based multiple-choice posttest (reproducing the results of Tennyson, Welsh, Christensen, and Hajovy, 1985). However, subjects using the previous example strategy performed significantly better than subjects using the previous response strategy on a paper-and-pencil posttest of concept definitions.

These results demonstrate that a method of response-sensitive (but computer-controlled) trial sequencing can produce better learning than random sequences. However, it is unclear if the computer-control method is superior to student control of trial sequencing. Furthermore, when programming response-sensitive sequencing strategies for other kinds of tasks, instructional designers will find very little guidance in the results of these experiments.

Sequencing Levels of Difficulty

For any given subject matter, instructional material may be organized and presented at various levels of difficulty. The designer must determine what aspects of a task or subject matter are difficult to students and how the content should be presented for optimal training effectiveness.

Guidelines. Authors of design guidelines make several conflicting recommendations about the sequencing of various levels of difficulty in CBI, including the following:

- simple material should be presented first and complicated material should be presented later,
- material that the student already knows should not be presented,
- the difficulty level of material should not vary during the session,
- the student should be allowed to control the difficulty level, and
- the student should not be allowed to control the difficulty level.

Most authors recommend that instructional presentations begin with simple material and progress to more complex material. Wheaton, Rose, Fingerman, Korotkin, and Holding (1976) assert that mastery of a task will be quicker if errors are prevented in the first few trials. Eberts and Brock (1984) agree by recommending that the early stages of training be designed so the accuracy rate of responding is relatively high. Wager and Wager (1985) recommend that designers sequence material from simple to complex and build on what the student already knows. Jonassen and Hannum (1987) advise designers to adapt the context of more difficult tasks to a content area familiar to the student and have the student progress from easy to more difficult problems. Finally, Alessi and Trollip (1985) state that computer-based tutorials should show students how to relate new information to what they already know.

These recommendations conflict with MacLachlan's (1986) advice to avoid the presentation of "information that students already know" and "provide a means of branching around information which is not needed by certain students" (p. 67). Similarly, the advice of Alessi and Trollip (1985) to keep item difficulty fairly constant throughout a computer-based drill session conflicts with recommendations to progress from easy to difficult problems. Ensuring errorless performance may be incompatible with keeping item difficulty constant throughout a session.

Kearsley (1986) advises designers to let the student determine the difficulty level of a presentation. However, other authors of design guidelines disagree. Asserting that student control of difficulty level is ineffective, Eberts and Brock (1984) recommend that the computer be programmed to determine the appropriate level of difficulty. Similarly, Jonassen and Hannum (1987) recommend the use of courseware

that analyzes each student's responses and adjusts the difficulty level accordingly.

Research. None of the recommendations about the sequencing of different levels of difficulty are supported by computer-based instructional strategies research. Only one report was located that addresses the organization of material according to difficulty level. Tennyson, Welsh, Christensen, and Hajovy (1985) compared two types of content organization: taxonomic and schematic. These authors define a taxonomic structure as the organization of lesson content that might be recommended by a subject matter expert. In a schematic structure, the lesson content is organized into a hierarchy of prerequisite skills and knowledge. An initial experiment revealed no differences between the two content organization strategies. In a second experiment, preliminary training in the operation of the computer was added to each content organization condition. Results of the second experiment demonstrated the superiority of schematic over taxonomic structure. This is weak support for the recommendation to present easy material first and difficult material later.

Graphics

Many instructional objectives can be met through the presentation of textual material. In some cases, however, text alone may be insufficient to achieve the training objectives; additional nontextual graphics may be required. In other cases, graphics may enhance training effectiveness by illustrating information more clearly and quickly than comparable textual presentations. Instructional designers should understand how computer graphics modify the training effectiveness of CBI. Such an understanding may support decisions about when graphics should be used and what sorts of graphics should be used to achieve particular training objectives.

Guidelines. Authors of instructional design guidelines are more consistent in their recommendations about the use of graphics than in other areas of computer-based instructional design. They offer the following guidelines:

- graphics should be used often,
- graphics should be used for highlighting important material,
- graphic information should be placed on the same screen as, and to the left of, textual material,

- high quality graphics are usually unnecessary and should be avoided, and
- animation should be used.

Several authors advise designers to use graphics rather than text whenever possible (Kearsley, 1986; Kearsley & Frost, 1985). Noting that illustrations and pictures are remembered more easily than words, MacLachlan (1986) recommends that designers use concrete rather than abstract representations. Braden (1986) advocates "a balance between iconic and digital displays, appealing to both right and left brain hemispheres" (p. 22). Buehner (1987) recommends a combination of verbal (e.g., text, voice) and spatial (e.g., graphics, pictures) material in CBI.

Several authors suggest the use of graphics to highlight important material (Jonassen & Hannum, 1987; MacLachlan, 1986). However, Jonassen and Hannum (1987) warn designers never to use flashing text nor more than three types of highlighting cues in any lesson. Similarly, Kearsley and Frost (1985) warn designers to use color sparingly for emphasis. Instead, they recommend using variations of type styles and sizes to highlight material.

Alessi and Trollip (1985) assert that graphic information should be presented on the same display as corresponding textual information. Wager and Wager (1985) agree, but suggest that when it is impossible for all the information to be on the same screen, the program should allow switching between the textual and graphic displays. Buehner (1987) recommends that spatial material be placed to the left of textual material to facilitate processing by the right hemisphere of the brain.

Some authors feel that excessive detail or realism should be avoided in graphic presentations (Alessi & Trollip, 1985) and that medium resolution graphics are sufficient (Jonassen & Hannum, 1987). Alessi and Trollip advise designers to provide "just as much detail as is necessary to convey the necessary information" (p. 194), but give no guidance about how to determine the optimal level of detail for a specific display. Claiming that lack of visual detail arouses curiosity and enhances training effectiveness, MacLachlan (1986) asserts that "one way to induce [curiosity] is to present the human subject with a blurred picture" (p. 65).

Finally, MacLachlan (1986) recommends animated graphics during tutorials. Kearsley (1986) recommends animation to convey sequence or cause and effect relationships.

Research. None of the research on the effects of graphics in CBI supports a recommendation to use graphics. For example, Reid and Beveridge (1986) examined the effects of illustrations accompanying text in a computer-based science lesson. Posttest scores showed no differences between subjects who viewed pictures plus text and those who viewed text only.

Surber and Leeder (1988) compared three types of feedback messages in a computer-based spelling drill. In a graphic feedback condition, correct responses were followed by a 3-second, multicolored, cartoon-style display of a word such as "WOW," "SUPER," or "GOOD WORK." Incorrect responses were followed by the word "NO" in the same graphic style and then the correct spelling of the word. In one of the non-graphic feedback conditions, responses were followed by the same words as in the graphic condition; however, the feedback appeared as normal text characters rather than graphic displays. In the other nongraphic feedback condition, correct responses were followed only by a presentation of the next trial, and incorrect responses were followed by a presentation of the correct spelling. The different forms of feedback, and consequently, the graphics, had no effect on the posttest scores or on the tendency of students to return to use the computer a second time.

Research support for the recommendation to use animation is mixed. Moore, Nawrocki, and Simutis (1979) presented computer-based lessons on audio psychophysiology to three groups of subjects. The lessons differed among groups in the level of complexity of graphic displays. For one group, graphics consisted of static alphanumeric characters and schematic drawings. For another group, graphics consisted of static line drawings of ear physiology. For the third group, graphics consisted of animated line drawings. No significant differences were found among groups on any of four posttests or in the time required to complete lessons.

Rieber and Hannafin (1986) compared textually presented orienting instructions with an animated version of the same instructions and found no differences. As noted previously, research suggests that orienting instructions may not enhance training effectiveness. Therefore, Rieber and Hannafin's research may not constitute a valid assessment of the utility of animation in CBI.

Animated graphics may be more useful than still graphics for training the perception of full-motion visual stimuli. McDonald and Whitehill (1987) found that full-motion graphics had a more beneficial effect on posttest performance than

still graphics for training the visual recognition of moving stimuli.

No literature was found that addresses recommendations about the placement of graphics on the display or the use of graphics for highlighting. Furthermore, no literature was found that addresses the assertion that high quality graphics are unnecessary (Alessi & Trollip, 1985; Jonassen & Hannum, 1987; MacLachlan, 1986).

Review of Material

Instructional presentations typically conclude with a review of instructional material. Remediation for an incorrect answer usually consists of a review of instructional segments pertaining to the test question. Instructional designers are concerned about whether the student or the computer should control the presentation of such reviews.

Guidelines. Some authors of instructional design guidelines recommend that students be allowed to control the presentation of reviews. For example, Cohen (1985) suggests that CBI programs be designed to enable students to go back through a lesson and reexamine the questions. Alessi and Trollip (1985) recommend that computer-based tests be designed in such a way that students can mark questions for subsequent review. Jonassen and Hannum (1987) tell the designer to give the student the option of reviewing material before answering questions.

In contrast, other authors recommend that the designer or the computer control the presentation of reviews. For example, Jonassen and Hannum (1987) advise designers to "select items again at intervals for review" (p. 10). Wager and Wager (1985) suggest a spaced review after the student first masters the material. Braden (1986) recommends that whole displays or major segments of displays be repeated to reinforce learning.

Research. The research shows no differences between student-control and computer-control review strategies. Ho et al. (1986) compared three review strategies during CBI: computer-controlled review, student-controlled review, and no review. In the computer-control strategy, a video summary was presented after each instructional segment. In the student-control strategy, each student chose whether or not to view the summary. In the no-review strategy, each instructional segment was followed immediately by the next instructional segment. Students using the two review

strategies had significantly higher posttest scores than students using the no-review strategy; however, there were no differences between the computer-controlled and student-controlled review strategies.

Hannafin and Colamaio (1986) compared three strategies of review during a computer-based lesson on cardiopulmonary resuscitation: designer-imposed strategy, learner-selected strategy, and linear strategy. For each strategy, 12 questions were presented during the lesson. In the designer-imposed strategy, if a question was answered correctly, the lesson advanced to the next segment. If the question was answered incorrectly, a review of the appropriate video segment was shown and the question was repeated. If the question was answered incorrectly on the second attempt, the correct answer was presented and the lesson advanced to the next segment. In the learner-selected strategy, the students were given options of reviewing each video segment, repeating each question, or advancing to the next segment regardless of whether their answers were correct or incorrect. Finally, in the linear strategy, students observed a preset sequence of video segments, and responses to questions were followed only by feedback about whether their answers were correct or incorrect. No video segment reviews, question repetitions, or sequence choices were presented to the students in this condition. Subjects in the designer-imposed and learner-selected conditions scored higher on a posttest than did subjects in the linear condition. However, there were no differences between scores for the designer-imposed and learner-selected strategies.

Finally, Kinzie and Sullivan (1988) compared two strategies for review following incorrect responses in a computer-based science lesson. A learner-control strategy permitted the student to decide whether to review material or to proceed with the lesson. A program-control strategy required each student to review the material. Posttests showed no differences between the two strategies.

Summary

A few of the experiments comparing methods of information presentation have produced results that can help designers of CBI. There is some support for increasing the stimulus display duration following correct responses so that advanced students may gradually take control of stimulus display duration (Tennyson & Park, 1984; Tennyson, Park, & Christensen, 1985; Tennyson, Welsh, Christensen, & Hajovy, 1985), but this contradicts the recommendations made by

Alessi and Trollip (1985), Eberts and Brock (1984), and Schneider et al. (1982). Tennyson's research also demonstrates an effective trial sequencing strategy for concept acquisition (Park & Tennyson, 1980, 1986; Tennyson, Park, & Christensen, 1985; Tennyson, Welsh, Christensen, & Hajovy, 1985) and provides weak support for sequencing lesson material from simple to complex (Tennyson, Welsh, Christensen, & Hajovy, 1985). Wightman and Lintern's (1985) review of empirical research suggests that part-task training should precede whole-task training only for tasks that can be partitioned temporally and recombined in a backward chaining procedure. Finally, one experiment demonstrated that animated graphics are more effective than static graphics for training in the perception of dynamic visual stimuli (McDonald & Whitehill, 1987).

Many of the published guidelines and recommendations are either not supported or not addressed by research. Experiments comparing lessons with and without orienting instructions or objectives have produced contradictory results (Hannafin et al., 1986; Ho et al., 1986; Rieber & Hannafin, 1986). Furthermore, the research does not address the assertion that orienting instructions and objectives limit the amount or breadth of learning. Research support for student control of trial sequencing comes from experiments with possibly inadequate comparison conditions (Barsam & Simutis, 1984; Gray, 1987). One experiment fails to support the recommendation to present information before practice (Lahey, 1981). No research was located that addresses recommendations to present concrete material before abstract material or to use temporal versus random sequencing strategies (cf., Barsam & Simutis, 1984). Recommendations to avoid presenting material that the student already knows and to avoid varying the difficulty level of material are not addressed by empirical research. There is also no research that addresses recommendations about student control of difficulty level, the use of graphics, graphics highlighting, placement of graphics, or quality of graphics. Finally, research shows no differences between student control and computer control of reviews.

Questions

One characteristic of nearly all training media is the presentation of questions to test the student's understanding of the subject matter presented during instruction. Textbooks, educational films, tapes, and lecturers frequently query students in an attempt to introduce lesson material, review material, or test for comprehension of material. Whether and when to present questions, how to present

questions, and how subjects should respond to questions are issues that must be addressed by designers of CBI.

Interactivity

Eberts and Brock (1984) advise that training systems should be designed such that students can interact with the training program. Hannafin (1985) suggests that the effective ingredients of interactivity are question, response, and feedback procedures. Response and feedback procedures are discussed in later sections. The importance of questions is discussed in the following paragraphs.

Guidelines. Most authors of instructional design guidelines agree that questions are essential in CBI. For example, Jonassen and Hannum (1987) advise designers to ask questions about material before, during, or after instruction. Wager and Wager (1985) assert that postlesson questions increase retention of material.

Research. Experiments designed to compare computer-based presentations with questions to those without questions tend to support the recommendation to include questions in CBI. There is one exception. McMullen (1986) compared three kinds of CBI programs that differed in the amount of interactivity and feedback. An information-only program presented textual material without any questions. A flashcard-type drill program presented questions after the text presentation. Subjects were required to enter an answer, but no feedback was provided for responses. An educational game program was identical to the flashcard-type drill, except feedback was provided for responses. Results showed no differences in posttest scores among the three programs.

On the other hand, Schaffer and Hannafin (1986) compared four versions of a videotape lesson that varied in the level of interactivity and complexity of feedback. In one version, subjects viewed the videotape without questions. In a second version, subjects viewed the videotape and were presented with questions but were provided no feedback for their responses. In a third version, subjects viewed the videotape and questions and were informed whether they were correct or incorrect in their responses. Finally, in a fourth version, subjects viewed the videotape and questions, were provided with feedback, and when incorrect, were shown a review of the section of videotape containing the information. Overall, posttest scores increased as a function of interactivity and feedback complexity.

Two experiments showed that presenting questions during a lesson is more effective than highlighting the same material. However, the effect only holds for the material that was highlighted or questioned. Schloss, Schloss, and Cartwright (1985) presented two versions of a computer-based lesson to groups of subjects. One version asked open-ended, sentence completion questions at various intervals during the lesson. The other version presented highlights, instead of questions, at various intervals during the lesson. A highlight was defined as a sentence entailing a question and its corresponding answer from the other version of the lesson. All subjects were given two posttests after viewing the lesson. One test contained 16 multiple-choice questions paralleling 16 of the questions (or highlights) from the previous lesson. The other test contained 16 questions paraphrased from the text of the previous lesson. Subjects who viewed the lesson with questions performed better on the former posttest than did the subjects who viewed the lesson with the highlights. There were no differences between groups on the latter posttest.

Schloss, Sindelar, Cartwright, and Schloss (1986) replicated the above study using multiple-choice questions, instead of open-ended questions. Again, subjects who viewed the lesson with questions performed better than subjects who viewed the lesson with the highlights on a posttest containing multiple-choice questions paralleling the questions (or highlights) from the previous lesson.

Prelesson Questions

Prelesson questions may function in a manner similar to orienting instructions or statements of objectives by preparing the student for the forthcoming lesson material. Recommendations and research about orienting instructions and objectives have already been discussed. However, some authors of instructional design guidelines have made specific recommendations about the use of prelesson questions.

Guidelines. Some authors recommend the use of prelesson questions; others recommend that prelesson questions not be used because they may interfere with comprehensive learning.

MacLachlan (1986) asserts that prelesson questions enhance learning. Jonassen and Hannum (1987) recommend that lessons begin with a pretest. They advise instructional designers to challenge students to answer questions presented at the beginning of a lesson.

In contrast, Wager and Wager (1985) believe that pre-lesson questions serve to focus attention on information related to answering the questions, but may hinder the retention of material that is not introduced by the questions. Hannafin and Hughes (1986) agree that learners tend to focus effort on information related to prelesson questions to the detriment of information not presented in the prelesson questions.

Research. Dalton, Goodrum, and Olsen (1988) compared three strategies for presenting prelesson questions during a computer-based lesson on division rules. Subjects in one group received a pretest of 20 items with feedback indicating whether each response was correct or incorrect. Subjects in a second group received the same pretest until five items were missed. After missing five items, the pretest ended and the lesson began. Subjects in a third group received no pretest. Posttest scores were significantly higher for subjects in the second group than in the first and third groups. Dalton et al. speculate that the 20-item pretest produced too much failure prior to the lesson and may have decreased student motivation. However, the brief pretest was superior to no pretest, suggesting that limited prelesson questioning enhances learning.

Question Types

Most computer-based instructional programs use multiple-choice questions, typically for the convenience of programming response processing and remediation routines. Yet there are many other types of questions that can be presented during CBI.

Guidelines. Authors of instructional design guidelines recommend that designers of CBI include the following types of questions:

- application questions,
- discrimination questions, and
- rhetorical questions.

Jonassen and Hannum (1987) recommend questions that require students to think about the application of the lesson material. Alessi and Trollip (1985) advocate questions that require the student to apply a rule or principle to a new situation rather than to recall or recognize answers. Wedman and Stefanich (1984) assert that test items should require the student to apply principles (or perform procedures) in ways consistent with how principles will be applied (or procedures performed) outside the learning situation. For

concept acquisition, Wedman and Stefanich recommend test items that require the student to discriminate between examples and non-examples of each concept. Jonassen and Hannum (1987) also recommend the use of rhetorical questions.

Research. Experiments evaluating various types of questions have not addressed the application, discrimination, and rhetorical questioning strategies recommended by Alessi and Trollip (1985), Jonassen and Hannum (1987), and Wedman and Stefanich (1984). Dalton and Hannafin (1987) found that subjects learned more from a lesson emphasizing application of concepts than from one that presented definitions of concepts without describing their application. However, this experiment did not compare question types. Similarly, Tennyson and his associates (Park & Tennyson, 1980, 1986; Tennyson, Park, & Christensen, 1985; Tennyson, Welsh, Christensen, & Hajovy, 1985) used a discrimination procedure similar to the one recommended by Wedman and Stefanich (1984). However, the focus of the Tennyson research was on trial sequencing strategies and not the effectiveness of discrimination questions in concept acquisition.

Schloss et al. (1986) compared three ratios of higher cognitive questions to factual questions in a computer-based lesson. They defined a higher cognitive question as one that requires a student to generate an answer that is not presented directly in the previous text. A factual question requires a student to recognize or recall information that is presented directly in the previous text. One version of the lesson contained 15 higher cognitive questions and 45 factual questions; a second version contained 30 higher cognitive questions and 30 factual questions; and a third version contained 45 higher cognitive questions and 15 factual questions. Posttest results revealed no differences among the three ratios.

Merrill (1987) compared computer-based lessons with high-level questions to lessons with low-level questions. Lessons with high-level questions produced higher posttest scores than lessons with low-level questions. Unfortunately, Merrill provides no definition or explanation of a high-level or low-level question. So, while Schloss et al. (1986) demonstrated that there is no need to distinguish between higher cognitive and factual questions when designing CBI, Merrill demonstrated a need to distinguish between high-level and low-level questions; however, insufficient explanation of that distinction reduces the usefulness of his research results.

Question Placement

In addition to decisions about whether to ask questions and the type of questions to ask, designers must decide when and where to present questions during a computer-based lesson. The issue of prelesson questions has been discussed previously; this section discusses the placement of questions within a lesson.

Guidelines. Authors of instructional design guidelines provide very little guidance about the placement of questions within a lesson. Alessi and Trollip (1985) suggest that questions should occur "frequently" during a lesson, and that only one question should appear on each display during a computer-based test. Wager and Wager (1985) recommend that each question be placed after the text passage or diagram to which it refers.

Research. Very little research has been conducted to support decisions about the placement of questions. Schloss et al. (1985) investigated the placement of questions in a computer-based lesson by comparing three ratios of questions to lesson frames. One program presented a question after every lesson frame (1:1); a second program presented three questions after every three lesson frames (3:3); a third program presented five questions after every five frames (5:5); and a fourth program presented all 90 frames before presenting all 90 questions (90:90). There were no differences in posttest scores due to the different question/frame ratios. The results of this research do not support the recommendation that questions should occur frequently during a lesson (Alessi & Trollip, 1985).

Number of Questions or Problems

Most CBI tutorials, drills, and tests are designed to be interactive by presenting discrete questions for students to answer or problems for students to solve. Simulations also may be divided into discrete segments for practice and feedback. Designers of CBI should present as many opportunities for interactivity as are necessary to achieve the training objective. However, it is not obvious how the number of questions or problems should be determined. The number could be fixed for all students receiving the training, or the number could be based upon each student's performance during the lesson. As with other decisions during CBI development, the student could be given control of the number of questions or programs presented.

Guidelines. Authors of instructional design guidelines make contradictory recommendations about the number of questions or problems required in CBI. Some authors claim that the student should control the number of questions or problems; others claim that the computer should be programmed to control adaptively the number of questions or problems.

Jonassen and Hannum (1987) advise designers to let students select the number of practice problems they want to work in a lesson. Specifically, they recommend that (a) the computer should ask students after each practice problem whether they want to work another practice problem or to discontinue the lesson, and (b) students should be allowed to stop working practice problems and return to other parts of the lesson whenever they choose. Similarly, Kearsley (1986) asserts that programs should allow students to skip questions.

Jonassen and Hannum (1987) also advise designers to provide more examples and exercises for students with low prior knowledge or low within-lesson performance; furthermore, they suggest that the number should be based upon student achievement during the lesson. The computer could either advise students to solve an appropriate number of problems, or it could simply present the appropriate number.

Research. Empirical research tends to support Jonassen and Hannum's latter recommendation about controlling the number of problems in CBI. Specifically, it appears most effective to program the computer to determine the number of problems necessary for each student to master the content. However, if the computer simply informs the students of the number of problems necessary for mastery, students may effectively select the number of problems themselves.

Tennyson (1980) compared three strategies for selecting the number of problems in a concept acquisition task. In the student-control strategy, the student decided when to stop the practice problems and take the posttest. In the computer-control strategy, the computer selected the number of problems based upon an assessment of the student's pretest and lesson performance. In the third strategy, called student control with advisement, the computer advised the student about the number of problems necessary for mastery based upon an assessment of the student's pretest and lesson performance, but the student decided when to stop the problems and to take the posttest. Students who were advised about the number of problems had higher posttest scores than students who controlled the number of problems without advisement. There were no differences in posttest scores

between students who were advised and students whose problems were controlled by the computer. However, students in the advisement condition selected fewer problems and took less time than students in the computer-control condition.

Tennyson (1981) and Johansen and Tennyson (1983) replicated this experiment with different age subjects and with a rule learning task instead of a concept acquisition task. The results were reproduced. From the Tennyson research, designers of CBI might conclude that student control over the number of problems is effective only if the students are advised about the number of problems to select. Results reported by Goetzfried and Hannafin (1985) appear to contradict this conclusion.

Goetzfried and Hannafin (1985) compared three versions of a computer-based lesson in mathematics. In the student-control version, the students controlled the presentation of the problems, but they were advised to solve at least four problems before advancing in the lesson. In the adaptive computer-control version, the students did not control the presentation of the problems; rather, they received additional instruction or problems according to the accuracy of their responses during the lesson. In the linear computer-control version, the computer presented a fixed sequence and number of problems. In this version, the students were not permitted to respond; instead, the problems were presented for student viewing, and the correct solution was presented on the following frame. There were no differences in post-test scores among these three versions, and the linear computer-control version took significantly less time to complete.

While the results of the Goetzfried and Hannafin experiment seem contradictory to those of the Tennyson research, the two procedures differed substantially. First, the algorithms for adaptive problems number selection were different. In the Goetzfried and Hannafin (1985) computer-control/adaptive condition, "each student was required to solve correctly all four problems in each section before advancing to the next divisibility rule" (p. 274). The Tennyson research used a complex algorithm developed from Bayesian probability theory (see Rothen & Tennyson, 1978). Consequently, the advisement procedures were different. Goetzfried and Hannafin advised each subject to "solve at least four problems correctly before advancing to the next section" (p. 274). Tennyson's advice came from the Bayesian algorithm. Finally, Goetzfried and Hannafin's subjects were seventh grade students enrolled in remedial mathematics classes; Tennyson's subjects were average high school and college students.

Answering Questions

The student's response in CBI might be an important variable in training effectiveness. Multiple-choice questions, the most common type, require students to select an answer by typing a single character or moving a cursor to the selected answer. Fill-in-the-blank questions require more typing. Simulations may require student responses of an entirely different nature.

Guidelines. Authors of instructional design guidelines offer the following, somewhat incompatible, recommendations about answering questions during CBI:

- the student should be permitted to see the answers to questions before responding,
- the student should not be permitted to see the answers to questions before responding,
- overt responses are not necessary and should not be required,
- overt responses are necessary and should be required,
- the student should be permitted to change an answer at any point during a quiz, and
- the student should control the sequence of questions.

Alessi and Trollip (1985) recommend that designers allow students to see the answer to a question upon request during computer-based drills. However, Jonassen and Hannum (1987) suggest that (a) the student should be required to generate an answer first and then receive feedback, and (b) the student should not be permitted to look back through the presentation for answers.

Jonassen and Hannum (1987) note that students can respond covertly as well as overtly. Asserting that overt responding is not necessary for learning, they recommend that designers give directions to students to stimulate covert responding. However, they contradict themselves when they state that "responses requiring multiple keypresses are required for deeper/more meaningful mental processing" (p. 11). Wager and Wager (1985) advise designers to ensure that the student make a substantive response before being shown the answer.

Kearsley (1986) recommends that programs permit students to change their answers to any question at any point during a pretest, posttest, or mid-lesson quiz. Furthermore, he advocates that programs permit students to back up and skip questions during pretests, posttests, and exams.

Research. None of the recommendations about student responses are addressed by computer-based instructional strategies research. One experiment suggests that a brief forced response-delay will enhance scores on multiple-choice tests. Stokes, Halcomb, and Slovacek (1988) presented computer-based quizzes to three groups of students in a psychology course. The groups differed in the period of forced response-delay following the presentation of a multiple-choice question: 0-sec, 30-sec, and 60-sec. Subjects in the 30-sec group had significantly higher quiz scores than subjects in the other two groups. However, there were no differences among groups on final examination scores or course grades. The brief response-delay appeared to improve immediate recognition of the correct answers, but it did not affect retention over a longer period.

Summary

The recommendation to include questions in CBI is generally supported by the research literature (Schaffer & Hannafin, 1986; Schloss et al., 1985; Schloss et al., 1986; but cf., McMullen, 1986). However, there is very little research to guide designers of CBI in making decisions about specific question and response strategies. There is some evidence that a brief prelesson quiz will enhance posttest performance (Dalton et al., 1988). Merrill (1987) has shown that high-level questions are superior to low-level questions, although the distinction between the two is unclear. Tennyson's research suggests that students can effectively control the number of practice problems if the computer is programmed to (a) analyze each student's achievement during a lesson and (b) present advice about the appropriate number of problems required for mastery (Johansen & Tennyson, 1983; Tennyson, 1980; Tennyson, 1981). Finally, there is some evidence that a brief, forced delay of response following the presentation of a multiple-choice question increases the probability that the student will answer correctly (Stokes et al., 1988).

Most of the guidelines and recommendations about question and response strategies remain unsupported by empirical research. No research was located to evaluate the relative effectiveness of application, discrimination, or rhetorical questions. There is no experimental support for presenting questions "frequently" during a lesson. No research was located to support the recommendations to permit students to see answers or to prevent students from seeing answers before responding. No experiments were found that address the issue of overt versus covert responding. Finally, no experiments

were found that address recommendations to permit students to change answers at any point during a quiz or to control the sequence of questions.

Programming Response Feedback and Remediation Strategies

If interactivity is a critical element of CBI, decisions about feedback and remediation are as important as decisions about the presentation of material and questions. Designers must determine what sorts of events should follow correct and incorrect responses, when these events should occur, and how these events should be presented on the screen. This section presents some of the guidelines and empirical research pertaining to feedback for correct and incorrect responses, remediation strategies, latency of feedback, and placement of feedback.

Feedback for Correct Responses

Instructional designers must decide what sorts of events, if any, should follow correct responses by students. The designer must decide if and how the computer should reinforce correct responding.

Guidelines. Authors of instructional design guidelines make the following three recommendations about feedback for correct responses:

- feedback is unnecessary and should not be used,
- feedback should be brief, and
- feedback should explain why the responses are correct.

Cohen (1985) asserts that feedback after a correct response is not as important as feedback after an incorrect response in CBI. However, Wager and Wager (1985) recommend a short affirmation of each correct response. They warn designers to avoid correct response feedback that is time-consuming. Conversely, Jonassen and Hannum (1987) warn designers to avoid feedback that simply indicates whether an answer is correct or incorrect. Instead, they recommend that correct answers be followed by feedback indicating that the answer is correct and explaining why it is correct. Wager and Wager (1985) suggest that the computer reinforce correct responses by displaying the answer in the context of the item whenever possible.

Research. No research was located that addresses recommendations about feedback for correct responses in CBI.

Feedback for Incorrect Responses

As with feedback for correct responses, designers of CBI must determine the most effective consequences of incorrect responses during a lesson. In addition to informing students that a response is incorrect, the computer is capable of providing remedial training or instruction. Therefore, it is important to determine the most effective methods for remediating errors in CBI.

Guidelines. Authors of instructional design guidelines provide the following recommendations for feedback and remediation of errors in CBI:

- corrective feedback is necessary and should be provided,
- feedback should be specific to the type of error,
- novel, entertaining, or auditory stimuli should not be used as feedback for incorrect responses, and
- multiple trials should be presented when an item is missed.

In addition, some authors make specific recommendations for remediation in cases of multiple incorrect responses and partially incorrect responses.

As stated previously, Jonassen and Hannum (1987) warn designers to avoid presenting feedback that simply indicates whether an answer is correct or incorrect. Feedback for incorrect responses should be corrective (Alessi & Trollip, 1985; Kearsley, 1986). Specifically, Wager and Wager (1985) advise that feedback should focus on correcting misconceptions represented by incorrect answers. Cohen (1985) agrees with this advice, noting that informational feedback is better than simple knowledge of results following incorrect responses.

Different types of errors should produce different types of feedback (Jonassen & Hannum, 1987). For example, Alessi and Trollip (1985) suggest a special method of feedback following errors in discrimination problems. Jonassen and Hannum (1987) suggest that if the specific error can be determined, feedback should indicate what error was made, why it was an error, and how it can be corrected. If the specific error cannot be determined, the computer should present the correct answer and an explanation of why it is correct.

Wager and Wager (1985) warn designers to avoid corrective feedback that is entertaining or novel. Jonassen and

Hannum (1987) add a warning never to use auditory cues to signal incorrect responses.

Alessi and Trollip (1985) recommend that questions answered incorrectly be repeated at variable intervals later in the instructional session. Jonassen and Hannum (1987) reinforce this recommendation by suggesting that the computer select items for review. If a program permits multiple opportunities to attempt a correct answer, Wager and Wager (1985) recommend providing increasingly informative feedback after each successive wrong answer. However, they caution designers to restrict the number of trials allowed before presenting the student with the correct answer or corrective feedback. If an answer is partially incorrect (and partially correct), feedback should prompt a correct response by telling students why their answers are incomplete (Wager & Wager, 1985).

Research. Several experiments have been conducted to examine the effects of different types of feedback and remediation strategies for incorrect responses. Consequently, there is some experimental support for the recommendation to provide corrective feedback rather than only knowledge of results. Two of the conditions in the Schaffer and Hannafin (1986) experiment, discussed previously, provide a test of error feedback complexity. Subjects in both conditions viewed a computer-based videotape lesson and answered questions. Subjects in one condition were only informed whether they were correct or incorrect in their responses. Subjects in the other condition were provided with similar feedback and, when answers were incorrect, were shown a review of the section of videotape containing information relevant to the question. Posttest scores were higher for subjects who were shown the reviews.

Similarly, Waldrop, Justen, and Thomas (1986) compared three types of feedback for responses on a 20-trial computer-based drill. In the minimal feedback condition, subjects were merely informed whether their responses were correct or incorrect. In the extended feedback condition, subjects were not only informed of the correctness of the answers, but were also provided with an explanation of the correct answer. In a third condition, minimal feedback was provided for the first two incorrect responses on a problem, but extended feedback was provided if the subject answered incorrectly a third time. Subjects in the extended feedback condition scored higher on a posttest than subjects in the minimal feedback condition. However, posttest scores of subjects in

the minimal plus extended feedback condition were no different than the scores of the subjects in the other two conditions.

Two experiments examined the complexity of remediation strategies for incorrect responses. Seigel and Misselt (1984) compared three strategies of feedback following incorrect responses in a flashcard-type drill for learning foreign words. In the first strategy, all incorrect responses were followed by a presentation of the correct answer. In the second strategy, errors were classified as out-of-list errors or discrimination errors. An out-of-list error occurred when a subject's incorrect answer (a translation) was a word that was not being taught in the lesson. A discrimination error occurred when a subject's incorrect answer was a word that was taught in the lesson but was incorrect on that particular trial. Out-of-list errors were followed by a presentation of the correct answer (as in the first strategy). Discrimination errors were followed by a presentation of the correct answer and the correct translation for the subject's incorrect response. The third strategy was identical to the second, except that discrimination errors were also followed by additional discrimination training. Posttest scores showed no differences between the first and second remediation strategies. However, subjects using the third strategy had fewer posttest errors than the other subjects.

Merrill (1987) compared two types of feedback for errors during a computer-based science lesson. Corrective feedback was a complete description of the correct answer. Attribute isolation feedback was not fully explained in the report. However, the attribute isolation feedback may have been less comprehensive, more specific, and more detailed than the corrective feedback. According to Merrill, "attribute isolation helps to focus attention on the critical and variable attributes of a concept" (p. 18). Results showed no differences in posttest scores between these two types of feedback.

Seigel and Misselt (1984) demonstrated that multiple repetitions of a problem following an incorrect response produced higher posttest scores than a single immediate repetition of the problem. They compared two strategies for repeating problems to which incorrect responses occur. In one strategy, the problem is repeated immediately following the incorrect response. In the other strategy, the problem is repeated on the next, 4th, and 9th trials following the error. Subjects exposed to the multiple repetition strategy made significantly fewer posttest errors than subjects exposed to the single repetition strategy. These results

support the recommendation to provide multiple opportunities to respond to a missed item.

The Waldrop et al. (1986) experiment, described previously, serves as a weak test of the recommendation that multiple errors be followed by increasingly more informative feedback (Wager & Wager, 1985). In this case, the results fail to support the recommendation; that is, the posttest scores for subjects in the minimal plus extended feedback condition were no different than the scores for the other two conditions. Thorkildsen and Friedman (1986) examined a different approach to remediating multiple incorrect responses. They compared two branching strategies termed extensive (EXT) and minimal (MIN). For both strategies, the first occurrence of an incorrect answer to a particular question is followed by a repetition of the question. After a second incorrect answer to the question, EXT branches to a simpler question than the original one, while MIN presents the original question for the third time. After a third incorrect response to a question, EXT presents an even simpler question with a prompt for the correct answer, while MIN presents the correct answer. Posttest scores showed no significant differences between these two branching strategies. However, subjects in the EXT condition spent significantly less time on the system. Recommendations about effective remediation of multiple errors will probably have to wait for definitive research on effective remediation of single errors.

No research was located that addresses the recommendations to avoid novel, entertaining, or auditory stimuli in error feedback (Jonassen & Hannum, 1987; Wager & Wager, 1985). Similarly, no research was located that addresses the recommendation to provide corrective feedback for partially incorrect responses (Wager & Wager, 1985). However, if a partially incorrect response is considered an incorrect response, research supports the recommendation to present corrective feedback (Schaffer & Hannafin, 1986; Waldrop et al., 1986).

Latency of Feedback

In addition to decisions about the kind of feedback for responses in CBI, designers must determine the temporal parameters of feedback. For example, designers must decide whether feedback should occur immediately after responses or after some delay. If delayed, designers must determine how much time should pass between the response and the feedback.

Guidelines. Authors of instructional design guidelines make the following contradictory recommendations about latency of feedback:

- immediate feedback should always be presented,
- delayed feedback should always be presented, and
- immediate feedback should be presented at some times and delayed feedback should be presented at other times.

Alessi and Trollip (1985) recommend giving immediate feedback for incorrect answers during drills. For tests, detailed feedback should be given immediately after the test. Cohen (1985) agrees with this recommendation, stating that immediate feedback is better than delayed or end-of-session feedback for students exhibiting low mastery of the material. Jonassen and Hannum (1987) also agree that immediate feedback is more effective for initial acquisition of material. Additionally, they assert that immediate feedback about consequences of decisions is more effective than delayed feedback. Wheaton et al. (1976) recommend that "information about the correctness of action should be available quickly" (p. 78), but that "delay of [feedback] has little or no effect on acquisition" (p. 77).

On the other hand, Cohen (1985) maintains that immediate feedback can impede the pace of learning, and MacLachlan (1986) asserts that students with higher skill levels may learn better under conditions of delayed feedback. Cohen recommends immediate feedback for the initial acquisition of material and for recognition or immediate recall of ideas. However, if students have prior knowledge of material, informational feedback should be delayed, and knowledge of results should be presented immediately after each response. End-of-session feedback should be provided when comprehension, long-term retention, and application of information are the training objectives. However, Cohen cautions that delayed feedback should be presented no longer than 15 or 20 minutes after the responses occur. After long periods without feedback, "the effect of the feedback becomes negligible and confusing" (Cohen, 1985, p. 36).

Jonassen and Hannum (1987) assert that end-of-session feedback facilitates learning of more abstract material, particularly for higher achievement learners. For computer-based simulations, Alessi and Trollip (1985) recommend immediate feedback (regardless of fidelity) with beginning students, and natural feedback (regardless of immediacy) with more advanced students.

Research. No research was found that supports the recommendations about latency of feedback in CBI. Gaynor (1981) presented computer-based math problems to four groups of subjects. One group received immediate feedback for responses. A second group received feedback after a 30-second delay. A third group received feedback only at the end of the session. A fourth group received no feedback for responses. No significant differences in posttest scores were observed among the groups.

One experiment appears to support a recommendation to delay corrective feedback during computer-based simulations. Munro, Fehling, and Towne (1985) compared two strategies for presenting error feedback and remediation during a computer-simulated air intercept controller task. For both strategies, errors were immediately followed by a tone and a brief message in an area of the computer display reserved for instructional messages. In one strategy, an additional instructional message was shown immediately following the error notice. In the other strategy, the instructional messages were not shown unless the subject requested them. Subjects using the latter strategy committed fewer errors overall and on the last ten trials than the subjects using the former strategy.

These results could be taken as support for a recommendation to delay corrective feedback during a simulation, or at least to present corrective feedback under the student's control. However, because of the dynamic nature of the air intercept controller's task, it is likely that subjects in the immediate feedback condition observed fewer of the instructional messages than subjects in the delayed feedback condition. The corrective feedback appeared in an area of the screen reserved for messages, not in the area of the screen that the subject had to view to perform the task. The comparison in this experiment may have been between an instructional message condition and a no-message condition, and subject control and delay of feedback were not the causal factors.

Placement of Feedback

In addition to the content and latency of feedback, instructional designers must decide how to structure the feedback on the computer display. Wager and Wager (1985) recommend that feedback be placed on the same screen as the question and below the student's response. The results of the Munro et al. (1985) experiment suggest that placement of

feedback is an important issue in the design of CBI. However, no research has been located to evaluate different strategies for placement of feedback.

Summary

As with the presentation of instructional material and questions, there is very little research to guide instructional designers in making decisions about feedback and remediation strategies. There is some experimental support for the recommendation to provide corrective feedback, instead of simple knowledge of results, following incorrect responses (Schaffer & Hannafin, 1986; Seigel & Misselt, 1984; Waldrop et al., 1986). Also, there is evidence that multiple repetitions of a problem following an incorrect response are more effective than a single repetition of the problem (Seigel & Misselt, 1984).

However, the research has not unequivocally determined whether and how different types of errors should be followed by different types of feedback (Merrill, 1987; Seigel & Misselt, 1984). No research was located to show that feedback for correct responses is unnecessary, should be brief, or should explain why a response is correct. No evidence was found that multiple errors should be followed by increasingly informative feedback (Thorkildsen & Friedman, 1986; Waldrop et al., 1986). No research was located that addresses recommendations to avoid novel, entertaining, or auditory stimuli in error feedback. No research was located to support any of the recommendations about latency of feedback in CBI or to evaluate different strategies for placement of feedback.

Other Guidelines about Instructional Strategies

Authors of instructional design guidelines give far more advice than the empirical research currently supports. For example, Kearsley and Frost (1985) warn designers to avoid cluttering the screen with too much information. Certainly, a program should not present subjects with ineffective visual displays, but how much information is too much? When is a screen cluttered? Braden (1986) and Kearsley and Frost suggest presenting only one primary concept or idea per visual display. This recommendation lacks empirical research support. Furthermore, Braden recommends that lists be restricted to seven or fewer items per display.

Several authors offer guidelines about the presentation of textual material. Alessi and Trollip (1985) recommend

normal upper and lower case text. Buehner (1987) asserts that double-spaced text is easier to read than single- or triple-spaced text. Wager and Wager (1985) warn designers to avoid abbreviations. They advise designers to spell words completely and use complete sentences. MacLachlan (1986) opposes the use of cliches and recommends the use of subordinate words and concepts. For example, MacLachlan prefers the use of a specific term, such as "raven," over the use of a more general term, such as "bird." No experiments were found that address such issues.

A few authors advocate mnemonics in CBI. MacLachlan (1986) specifically recommends the use of rhyme, rhythm, and the method of loci in textual material. Jonassen and Hannum (1987) suggest that designers periodically include directions for the student to "generate mental images of the content" (p. 10). The use of mnemonics in learning has empirical support in traditional educational research. There is no reason to assume that the value of mnemonics would be less for CBI.

Several recommendations about instructional strategies are so vague that their value to designers is questionable. For example, Eberts and Brock (1984) recommend that CBI include "examples and analogies to make the training effective" (p. 280). They also advise designers to make the learning intrinsically motivating by utilizing challenge, fantasy, and curiosity in the learning environment. Finally, they recommend that the computer display should provide information in a manner that can be used to form an accurate internal representation of the system or concept being trained. Kearsley and Frost (1985) advise designers to "organize information functionally on the screen as much as possible to reduce confusion and unnecessary cognitive processing" (p. 10). Finally, Jonassen and Hannum (1987) suggest that designers "organize material to an appropriate top-level structure: description, compare/contrast, temporal, explanation, definition, example, problem solution, causation" (p. 10).

Discussion

Although there are some consistencies in the literature, the guidelines and research in computer-based instructional strategies are characterized by contradictions. In some cases, authors of instructional design guidelines contradict each other with their recommendations. In other cases, empirical research contradicts the experts' recommendations. Many of the recommendations, however, lack empirical research altogether.

Each guideline discussed in this review was classified by (a) whether authors of instructional guidelines made another recommendation that contradicted the guideline and (b) whether empirical research supports the guideline, contradicts the guideline, or does not exist. The guidelines and their categories are listed in Table 1. If any guideline contradicted another guideline, both of the guidelines were classified under "Some Authors Disagree." Otherwise, the guidelines were classified under "No Disagreement Among Authors." If empirical research supports or contradicts a guideline, the guideline was classified under "Research

Table 1

Listing and Classification of CBI Guidelines

Guideline	No Disagreement Among Authors	Some Authors Disagree	Research Supports	Research Contradicts	Insuffi- cient Research
1. Present questions	X		X		
2. Corrective feedback is necessary for incorrect responses	X		X		
3. Multiple trials should be presented when an item is missed	X		X		
4. Present prelesson questions		X	X		
5. Program the computer to control adaptively the number of trials		X	X		
6. Use graphics often	X			X	
7. Provide increasingly informative feedback for successive errors	X			X	
8. Train under mild speed stress		X		X	
9. Present information before practice		X		X	
10. Randomize the sequence of material		X		X	
11. Part-task training should precede whole- task training		X		X	
12. Permit student to control the presenta- tion of reviews		X		X	

Table 1

Listing and Classification of CBI Guidelines (Continued)

Guideline	No Disagreement Among Authors	Some Authors Disagree	Research Supports	Research Contradicts	Insuffi- cient Research
13. Program the computer to control the presentation of reviews		X		X	
14. Use graphics to highlight important material	X				X
15. Place graphic information on the same screen as and to the left of the text	X				X
16. High quality graphics are unnecessary	X				X
17. Use animation	X				X
18. Present application questions	X				X
19. Present discrimination questions	X				X
20. Present rhetorical questions	X				X
21. Present questions frequently	X				X
22. Present each question after the text passage to which it refers	X				X
23. Permit student to change answers at any point during a quiz	X				X
24. Permit student to control the sequence of questions	X				X
25. Feedback should be specific to the type of error	X				X
26. Do not present novel, entertaining, or auditory feedback for errors	X				X
27. Place feedback on the same screen as the question	X				X

Table 1

Listing and Classification of CBI Guidelines (Continued)

Guideline	No Disagreement Among Authors	Some Authors Disagree	Research Supports	Research Contradicts	Insuffi- cient Research
28. Orienting instructions are ineffective		X			X
29. Present orienting instructions		X			X
30. Lesson objectives are ineffective		X			X
31. Lesson objectives limit learning		X			X
32. Present lesson objectives		X			X
33. Present lesson objectives as a student-controlled option		X			X
34. Permit student to control duration of questions and graphics		X			X
35. Shorten tasks without losing important aspects for training		X			X
36. Always permit student to control the sequence of instruction		X			X
37. Never permit student to control the sequence of instruction		X			X
38. Conditionally permit student to control the sequence of instruction		X			X
39. Present concrete material before abstract material		X			X
40. Use chronological ordering of material		X			X
41. Present simple material before complex material		X			X
42. Do not present material that the student already knows		X			X
43. Do not vary the difficulty of material during the session		X			X

Table 1

Listing and Classification of CBI Guidelines (Continued)

Guideline	No Disagreement Among Authors	Some Authors Disagree	Research Supports	Research Contradicts	Insuffi- cient Research
44. Permit the student to control the difficulty level of material		X			X
45. Do not permit the student to control the difficulty level of material		X			X
46. Prelesson questions limit learning		X			X
47. Permit student to control the number of problems		X			X
48. Permit student to see answer before responding		X			X
49. Require student to respond before presenting answer		X			X
50. Present questions that evoke covert responses		X			X
51. Require overt responses		X			X
52. Feedback for correct responses is unnecessary		X			X
53. Feedback for correct responses should be brief		X			X
54. Feedback for correct responses should explain why responses are correct		X			X
55. Immediate feedback should always be presented		X			X
56. Delayed feedback should always be presented		X			X
57. Present immediate feedback sometimes and delayed feedback at other times		X			X

Supports" or "Research Contradicts," respectively. Often, a single experiment exists to support or contradict a guideline. Such evidence may or may not be considered conclusive, depending upon the strength of the research and the specificity of the guideline. Finally, a guideline was classified under "Insufficient Research" if (a) empirical research produced mixed results and further research is required, (b) empirical research is inconclusive because of inadequate experimental designs, or (c) empirical research on that guideline was not located.

In the following sections, each guideline is evaluated in terms of its usefulness for computer-based instructional design. Some of the guidelines are self-evident and do not require empirical validation. Other guidelines are stated in terms that are so general that it is not possible to evaluate their usefulness. Some of the guidelines are very specific, and an evaluation of their generalizability is required. Generalizability may exist on different dimensions, and CBI researchers and designers need to understand the important dimensions in educational technology. The present review and interpretation of the literature suggests that there are at least three important dimensions along which generalizability may vary: (a) training format (e.g., tutorials, drills, or simulations), (b) training objectives (e.g., acquisition vs sustainment training, verbal/conceptual vs nonverbal/procedural training), and (c) target population (e.g., high school or college students, military personnel, industrial workers).

Guidelines Supported by Research

Guidelines 1-5 in Table 1 are supported by empirical research. Authors of guidelines agree that CBI should present questions, corrective feedback for incorrect responses, and multiple trials for items that are answered incorrectly. The recommendation to present questions applies principally to tutorials. However, questions might also be incorporated into some types of training simulations, such as those designed to train complex decision-making skills.

The recommendation to present corrective feedback means that feedback that simply informs the student of whether an answer is correct or incorrect is not as effective as feedback that presents more information. Precisely how much information is sufficient probably depends upon the instructional content, the purpose of the instruction, and the type of student. The recommendation to present multiple problems following incorrect responses is supported by a single

experiment. The generalizability of this guideline needs to be evaluated.

Although some authors do not agree that CBI should present prelesson questions or that computers should be programmed to control adaptively the number of trials, empirical research suggests that these strategies are effective. The recommendation to present prelesson questions is supported by a single experiment. Therefore, the generalizability of this guideline should be evaluated. The recommendation to program the computer to control adaptively the number of trials is supported by a series of experiments in which age of student and instructional content have varied.

Guidelines Contradicted by Research

Although authors agree that designers of CBI should use graphics often and provide increasingly informative feedback for successive errors (guidelines 6 and 7, Table 1), empirical research fails to support these guidelines. However, the experimental evidence is not strong enough to justify complete rejection of these guidelines. For example, while experiments that compare graphics to text have not produced results suggesting that graphics should be used often, no research has been located to show that graphics should be avoided. Whether graphics are useful in CBI probably depends upon many other factors, such as the training format, training objectives, and target population.

The recommendation to provide increasingly informative feedback for successive errors was contradicted by several experiments. Consequently, its rejection may be warranted. However, it seems reasonable to suppose that errors made repeatedly require more extensive remedial effort than errors made only once or twice.

Some authors do not agree with the next six guidelines in Table 1 (guidelines 8-13), all of which are contradicted by empirical research. Again, the experimental evidence does not necessarily justify rejection of each guideline. For example, the recommendation to train under mild speed stress is contradicted by several experiments showing that correct responses should be followed by increases in stimulus display duration. However, these experiments were not explicitly designed to test the effectiveness of speed stress during training. Certainly, the recommendation is sensible if the purpose of the training program is to increase the speed with which a student performs a task. Further research is required to determine whether or not speed stress during

training is useful when increasing performance speed is not a training objective.

Only one experiment contradicts the recommendation to present information before practice (Lahey, 1981), but the validity of this guideline is logically questionable. By definition, computer-based drills and simulations emphasize practice. Often, the presentation of information is simultaneous with practice. Only tutorials may require information to be presented separate from practice. In addition to the experiment by Lahey, the demonstrated effectiveness of drills and simulations contradicts the recommendation to present information before practice.

The recommendation to randomize the sequence of instructional material is contradicted by other recommendations about sequence and by the results of Barsam and Simutis (1984). Randomization can occur at several levels, and at some levels it may be necessary for effective instruction. The response choices in a multiple-choice question can and should be randomized, and ordinarily, the order of items in a test should be randomized. However, there are some types of instructional material that simply cannot be learned if the material is presented in a random manner. When sequence of instruction is a critical training variable, the most effective sequence must be determined.

The general consensus about whether part-task training should precede whole-task training is that it depends upon the partitioning strategy for the particular task (Wightman & Lintern, 1985). However, Wightman and Lintern note that the effects of the segmentation strategy may be confounded with the backward chaining technique used in most of the training effectiveness research. Further research is required to separate the effects of these two variables.

Finally, the contradictions in recommendations about the presentation of reviews may be resolved if designers consider that there are several different kinds of reviews. Instructional material can be reviewed at the end of lengthy instructional segments prior to questioning or ending a session. Reviews may follow incorrect responses during a drill or test. Questions or items in a drill may be reviewed. Whether or not students should control the presentation of reviews may depend upon which type of review one is considering.

Guidelines Lacking Research Support

The remaining guidelines in Table 1 have been insufficiently addressed by empirical research. The next two sections discuss the guidelines that are not contradicted by any other guideline (guidelines 14-27), and those that are contradicted by another guideline (guidelines 28-57).

No disagreement among authors. Research has not been located to compare strategies of highlighting, but there is no reason to assume that the use of graphic highlighting would be any less effective than other methods, such as capitalizing and underlining. Computer display design has been studied in other settings (Brown, 1988), and computer-based instructional designers might benefit from the results of that research.

It would be simple enough to test the recommendation to place graphic information on the same screen as, and to the left of, text. However, it seems doubtful that any distinction between right and left brain specificity of visual processing would result in performance differences during CBI that have practical significance. When a student attends to a visual stimulus, such as text or graphics on a computer screen, that stimulation impinges on receptors in the fovea. The fovea must shift so frequently during inspection of stimuli on the screen that any spatial differences in placement of text and graphics may be irrelevant for training effectiveness.

The assertion that high quality graphics are unnecessary has not been adequately tested. This is an important area for research, because high quality graphics may be more expensive to produce than low quality graphics. The quality of graphics required for effective training may be an issue of fidelity. The general consensus is that maximum physical fidelity (between a computer graphic and the real-world stimulus that the graphic represents) is not always necessary for effective training. However, it is inappropriate to say that high quality graphics are never necessary. It seems reasonable to assume that different types of images used for different purposes in training require different levels of graphic quality. Further research is required to elucidate the relationship among types of images, training functions of images, and quality of graphics.

Similarly, animated graphics are often more expensive to produce than static graphics. The results of McDonald and Whitehill (1987) suggest that animation is required for effective training in the perception of dynamic visual

stimuli. However, it is not clear whether animation is worth the cost for many other applications of CBI.

Application, discrimination, and rhetorical questions are sensible alternatives to simple recall questions. Research has shown that application and discrimination training are effective approaches in CBI. It is likely that application and discrimination questions would enhance training similarly. Rhetorical questions may serve as useful stimuli in a training program. However, by definition, it would be impossible to record, evaluate, and remediate a response to such a stimulus.

Although one experiment showed no differences between tutorials with different frame-to-question ratios (Schloss et al., 1985), these results are surprising, and the recommendation to present questions frequently should be researched further. Frequent presentation of questions facilitates more interaction with the training device. If interactivity is a critical aspect of training, it is reasonable to assume that more frequent questions would be effective.

No one disagrees that questions should be presented after the text passages to which they refer, assuming that the recommendation does not refer to prelesson questions. It seems sensible to evaluate or reinforce students' knowledge of a fact only after they have been presented with that fact. Prelesson questions, however, have been shown to enhance training effectiveness (Dalton et al., 1988). Although further research is required, it is likely that intralesson questions presented prior to a text passage are also effective.

Although this guideline has not been tested, it seems sensible to permit students to change answers at any point during a computer-based quiz. The only exceptions might be programs designed to train students to answer questions rapidly under time pressure.

No one has contradicted the recommendation to permit students to control the sequence of questions, and no research has been located to address that recommendation. If the sequence of questions is unimportant for training effectiveness, there is no reason why students should be restricted from modifying it. However, further research is required to elucidate the effects of various sequential strategies before declaring that sequence is an unimportant variable.

The guideline that feedback should be specific to the type of error has been evaluated in experiments with mixed results. If different types of potential errors can be identified during instructional design, it would be possible to program different types of feedback. However, the added cost of such an effort justifies further research to determine the level of specificity required in feedback.

No research was located on the effects of novel, entertaining, or auditory stimuli in error feedback. A stimulus that is novel or entertaining to a designer might not be so to a student. Furthermore, students of different ages may respond to such stimuli in different ways. Presumably, the recommendation to avoid auditory stimuli is made to prevent a student's embarrassment when making an error in a CBI classroom. However, many CBI programs present auditory stimuli as a part of the training. Headphones may be used to prevent the stimuli at one workstation from disrupting the training at nearby workstations. Under such conditions of privacy, there is no reason to assume that auditory stimuli would be any less effective than visual stimuli for remediating errors.

The guideline to place feedback on the same screen as the question assumes that such feedback always fits on one screen. If feedback is extensive, it may be necessary to present it in several screens.

Some authors disagree. Authors of instructional design guidelines contradict each other in their recommendations about the presentation of lesson objectives and orienting instructions. Guidelines about orienting instructions seem self-evident. It cannot be denied that CBI using novel equipment or complicated interactivity routines must provide instructions on how to use the equipment or interact with the program properly. When the equipment is simple to operate or the interactivity routines are obvious, orienting instructions are not required. Because of research with other educational media, some authors suggest that lesson objectives are ineffective or may limit the amount of material retained from CBI. Other authors recommend that lesson objectives (and orienting instructions) be presented, at least as a student-controlled option. These assertions have not been tested with CBI. If lesson objectives are ineffective or detrimental to training effectiveness, they should not be presented. Further research is required to evaluate these guidelines.

The recommendations to permit students to control the duration of questions and graphics are contradicted by

recommendations to train under speed stress or to program the computer to control stimulus display durations. Visual stimuli should be presented long enough for students to adequately view them. The best strategy for determining stimulus duration probably depends upon the type of training involved.

It makes sense to shorten tasks, if this can be done without losing important aspects for training. For most tasks, more training means more learning. More trials can be presented if unnecessary time-consuming events are eliminated from the training. Designers must empirically determine which events are important and which are unnecessary for the specific tasks to be trained.

Guidelines 36-40 in Table 1 are about sequence of instructional material. Authors of design guidelines disagree about whether students should control the sequence of instruction. Research must be conducted to determine if sequencing is an important variable for training effectiveness and what sequence is most effective for particular applications. If sequence is an important training variable, students should not be permitted to control it. Students are no better than trained instructional designers (and probably worse) at determining the most effective sequences of instruction. If an effective sequence can be determined, that sequence should be presented. Whether or not any particular sequence (such as concrete material before abstract material, or a chronological sequence) is effective depends upon the nature of the instructional material. Most material can be presented in several different sequences. The design of CBI must include formative evaluations to determine the most effective sequences.

Sequencing instructional material according to difficulty level is a related issue (guidelines 41-45). For most material, simple material may serve as a prerequisite for more difficult material. In such cases, the prerequisite material should be presented first. Research is required to determine when the difficulty level should be raised during CBI for each application. Again, it makes no sense to depend upon students to determine the most effective level of difficulty for training. However, it is possible that students using CBI for skill sustainment training could effectively select their own difficulty level. This possibility should be evaluated in empirical research.

One experiment has shown that limited prelesson questioning enhances learning and extensive prelesson questioning could be detrimental (Dalton et al., 1988). However, similar to the assertion about lesson objectives, the assertion that

prelesson questions limit learning requires further research (guideline 46).

The recommendation to permit students to control the number of problems (guideline 47) is contradicted by the empirically supported recommendation to program the computer to control adaptively the number of problems. In fact, the research shows no differences between adaptive computer control and student control when students are advised about the number of problems required to master the material. Adaptively generated advice appears to be a necessary component of the effective student-control strategy. If students follow such advice, there is no reason to prevent them from controlling the number of problems. Whether or not students will follow the advice is a topic for further research.

Guidelines 48-51 in Table 1 address the importance of a student's response in CBI. If the interaction between student and computer is an important phenomenon in training, the nature of the student's response is important. Permitting students to see answers before attempting to answer questions themselves is one form of interaction. Whether this type of interaction is as effective as requiring an overt response and then providing feedback must be determined in empirical research.

The focus of feedback research has been on remediation of errors. Guidelines for designing feedback for correct responses have not been evaluated (guidelines 52-54). Certainly, students should be informed when they have made a correct response. Therefore, it is erroneous to say that feedback for correct responses is unnecessary. However, whether this feedback should be brief or extensive may depend upon other training issues. Further research is required in this area.

Whether feedback should be presented immediately following a response or should be delayed for some time period probably depends upon other training issues (guidelines 55-57). Research in basic learning processes suggests that immediate feedback is most effective for most training applications. The generalizability of this conclusion has not been sufficiently explored.

Conclusion

The implications of this review may differ for the CBI designer and the educational technology researcher. Both

should be aware of the contradictions and potential limitations of the recommendations in the literature. Research can be designed to address the current gaps in our knowledge of computer-based instructional strategies; in the meantime, designers must continue to develop material to meet current training and educational requirements. Instructional designers should recognize when a particular strategy is being applied in a case that potentially tests the generalizability of a recommendation or research result. Consequently, formative and summative evaluations during CBI development will contribute to the body of knowledge in instructional design strategies (Gagné et al., 1988). Educational technology researchers should identify the important dimensions along which the generalizability of instructional strategies may vary. Several have been suggested here, but a clearer exposition requires further research.

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